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in a Two-Phase Field

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BEHAVIOR OF A ROTOR IN A TWO-PHASE FIELD.

By C. L. Housel.

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE IN

ELECTRICAL ENGINEERING

in the

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS.

Presented JUNE, 1901.

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Oscar Lloyd Housel

ENTITLED Behavior of a Rotor in a Two-Phase Field

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Electrical Engineering.

Wm. L. Aldrich

HEAD OF DEPARTMENT OF

Electrical Engineering

1901
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PREFACE.

In deciding upon the subject for this thesis there seemed to be many reasons for selecting the one chosen. The use of induction motors is advancing in all lines of the industrial applications of electricity. Among such fields of application may be named: pumps, fans, blowers; printing presses; all classes of machine tools as milling, boring, shaping machines, lathes and drills; elevators, hoists and cranes. The outlook for its future is very promising, especially along street railway development.

The writer being especially interested in the transmission of power in mills and factories, selected the induction machine as a representative motor for this field. The facilities in the Electrical Engineering Laboratory also being provided for this work the experiments were carried out as herein indicated.

Tests were made on a Westinghouse, type C, two-phase, 60 ∞ , two horse-power induction motor. These experiments were carried on at different voltages as 105, 110, and 115 volts. The torque was varied in each case from zero to a certain maximum depending on the voltage.

The original intention was to make similar tests at 210, 220, 230, and 420, 440, 460 volts. For lack of time the latter series had to be omitted. It was expected that tests would also be made upon a Westinghouse type F, two-phase, 60 ∞ , three horse-power, variable speed induction motor. The



manufacturers were unable to ship this motor in time to begin the experiments.

In conclusion it may be said of the thesis investigations carried out as shown in the following pages:

- (1.) Extremely light weight, 250 pounds rated, for maximum power which it was found capable of developing, 3.4 Kilo Watts at 115 volts.
- (2.) The slip was, at normal rated load, about $6 \frac{1}{2}$ per cent.
- (3.) Under all conditions of the trials with various impressed voltages the starting torque was in excess of that usually allowed for machines of this size.
- (4.) The real efficiency showed a high maintained value of about 80 per cent. in general for a wide range of load, from about 50 per cent. underload to about 25 per cent overload.
- (5.) The power factor showed a satisfactory maintained value of about 85 per cent. from about full load to maximum overload.

SYLLABUS.

INDUCTION MOTORS.

I. -DEVELOPMENT OF THE INDUCTION MOTOR.

- 1.-Production of rotary or rotating magnetic fields; 1, 2,
or 3-phase.
- 2.-Interaction of magnetic field upon its induced current in
conductor.

Spinning disks Babbage, Arago, Faraday; wattmeter disk.

Eddy currents in spinning disks of copper and aluminium

Eddy currents in copper or aluminium cylinder,

continuous or split, as the rotor of the induction

motor, of squirrel-cage type.

- 3.-Early types of induction motors: 1, 2, and 3-phase.
- 4.-Example of principles of induction motor in wattmeters.

II. -THEORY AND PRINCIPLES.

- 1.-General principles underlying action of induction motor.
- 2.-Relation of induction motor, general and as two-phase:-
 - (a) to the alternating current transformer.
 - (b) to the direct current shunt motor.
- 3.-Theory and principles of special types of induction motors.

Single-phase: Brown, Wagner; Two-phase, Ferraris, Tesla;

Three-phase, General Electric.

III. -CLASSIFICATION.

- 1.-General: Rotary induction apparatus which consists of
primary and secondary windings, rotating with respect

to each other, comprising:

- (a) Induction motors.
- (b) Induction generators.
- (c) Frequency changers.
- (d) Rotary phase converters.

2.--Induction motors with variable resistance in armature or rotor.

3.--Induction motors with short-circuited armatures, squirrel-cage rotors.

IV. -ELEMENTS OF DESIGN.

1.--Allowances, constants and coefficients.

- (a) Leakage, leakage factor and air gap.
- (b) Inductance of stator and rotor.
- (c) Core losses, hysteresis and eddy currents.
- (d) Copper losses: Equivalent resistance -- $\frac{I^2 R}{I}$ for calculating copper losses: value of this method: dependance on voltage, load, frequency, etc.

2.--Electric and magnetic circuits of machine.

3.--Mechanical and structural details.

V. -CONSTRUCTION.

1.--Electrical details, windings, diagrams, insulation, etc.

2.--Magnetic considerations, lamination of cores, balance of rotor.

3.--Mechanical and structural details; static and dynamic balance of rotor.

4.--Description of induction motors in commercial use.

5.-Accessories:

Phase-splitting devices for single phase motors;

Starting and switching-in arrangements, compensators.

Variable speed control, multi-speed motors.

Use of resistance, induction and capacity in starting and in control.

VI. -INSPECTION.

1.-Mechanical, electrical, and magnetic.

VII. -OPERATION.

1.-Starting:effect and value of starting devices:torque, current.

2.-Functional working:normal and overload conditions.

3.-Effect of varying the impressed E.M.F.,on starting and operation loaded.

4.-Capacity of 2- and 3-phase machines operated single-phase.

5.-Reversal of 2- and 3-phase motors.

6.-Faulty working and remedies.

7.-Influence of frequency,speed and slip:variable speed performance.

8.-Regulation,control of voltage;effect on lighting circuits.

VIII. -PERFORMANCE AND TESTING.

1.-Principles and methods employed:electrical,magnetic, and mechanical.

2.-Errors,precautions,precision of measurements.

3.-Effect of variables on performance:voltage,frequency, phase shifting.

4.-Functional performance: characteristics, losses, efficiency.

5.-Starting performance, starting and crossing devices:

current, torque, etc.

6.-Electrical characteristics of performance: current, E.M.F.,

power and power factor, true and apparent efficiency,

torque efficiency, phase difference, idle or "wattless"

energy.

(a) Losses, determination and separation of.

(b) Impressed E.M.F. - dependence upon of speed,

maximum torque, slip, power, power factor, efficiencies

and various losses.

(c) Frequency, - Dependence upon, of speed, maximum

torque, slip, power, power factor, efficiency and

various losses.

(d) Current values: magnetizing current, idle or

"wattless" current, starting current, induced rotor

currents.

7.-Magnetic determinations: induction, leakage, leakage factor,

air gap, core losses.

8.-Performance, general characteristics of, - electrical,

magnetic, mechanical.

(a) Deductions and conclusion from behavior, performance and test.

(b) Do results of test corroborate principles of action and constants used in designs?

IX. -SPECIAL STUDIES OF INDUCTION MOTORS.

- 1.-Analysis of action of induction motor,application of diagrams, etc.
- 2.-Establishment of laws of induction motor, electrical, magnetic, and mechanical.
- 3.-Phase splitting and phase splitting devices.
- 4.-Induction motor or an induction generator.
- 5.-Concatenation of induction motors.
- 6.-Induction motors as frequency changing transformer.
- 7.-Influence of wave form upon iron losses.

BEHAVIOR OF A ROTOR IN A TWO-PHASE FIELD.

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Experiment 2.	Performance at 110 volts.
Experiment 3.	Performance at 105 volts.

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CHAPTER I.

DEVELOPMENT OF THE TWO-PHASE INDUCTION MOTOR.

Art. 1. PRODUCTION OF A TWO-PHASE ROTATING MAGNETIC FIELD.

It is a well known fact that a current traversing a coil of wire causes a field of force to be set up at right angles to the conductor. Suppose that this current is an alternating current, periodically varying from a positive maximum to a negative maximum. The field of force set up in the coil will also vary in a like periodic manner and be in quadrature with the electromotive force of the current. The electromotive force and the current would be in phase if it were not influenced by eddy currents in the iron core and secondary currents induced in the adjoining coils which oppose the primary action and cause the current to lag in phase behind the electromotive force.

Now consider two similar coils placed so that their planes are at right angles to each other, as in fig. 1.* Send

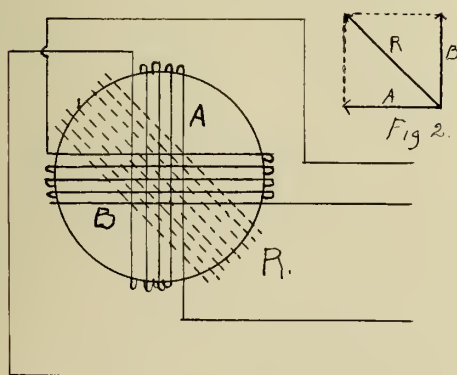
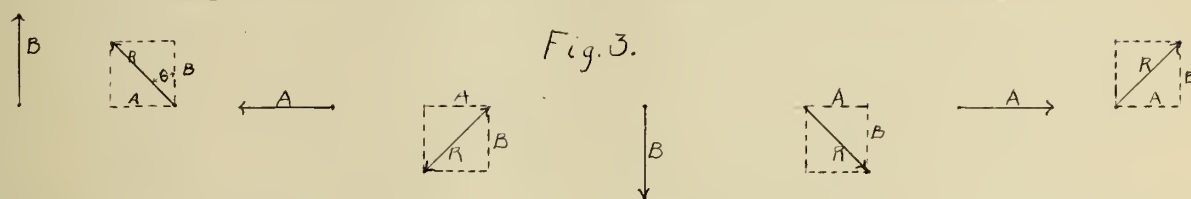


Fig. 1.

through each coil a direct current. A field will be induced at right angles to the plane of each coil. These fields can be represented by a vector. Since the coils are at right angles these vectors will be also at right angles. From these

*"The Rotary Magnetic Field," American Electrician. Vol. XIII.

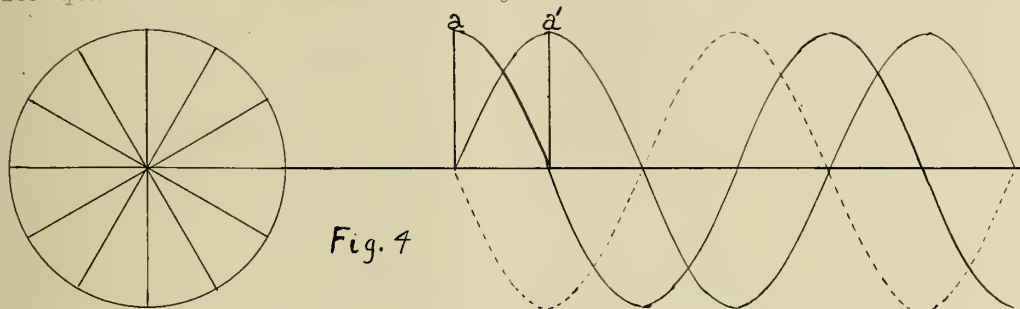
vectors by completing the parallelogram the resultant can be found, see fig. 2. Next take the case of two alternating currents impressed upon the coils, the currents being 90°



apart, or in other words, one is a maximum when the other is zero, and vice versa. Suppose that the current in coil B is maximum when the current in coil A is zero, which will be the case when in quadrature. Then the field induced by it, (neglecting for the time, eddy currents and self-induction,) is a maximum and in quadrature with the current, it can therefore be similarly represented by a vector. When the magnetic field of coil A is zero that of coil B will be the resultant field. In a certain length of time this vector will decrease and the vector representing the flux in coil A will increase. Completing the parallelogram, as in fig. 3, and drawing the diagonal the direction and magnitude of the resultant flux can be found. This resultant makes an angle θ with the former resultant flux; and as the flux in coil A increases the flux in coil B will decrease, the resultant will then move over toward the vector representing the flux in coil A, and when the flux in coil B is zero the vector will represent the flux in coil A and also the resultant flux.

The direction of rotation of this resultant vector depends upon the initial relation of the flux in coil A to

the flux in coil B. In fig.4, two waves of electromotive force are shown in quadrature; and since the flux is similarly in quadrature it would vary in like manner. For the flux in



coil A there are two conditions, when the flux in coil B is a maximum, at the point a, the flux in coil B is zero. As this flux decreases the flux in coil A must increase toward either a negative maximum or a positive maximum, it is, therefore, due to this feature that the direction of rotation is determined, since negative values of the flux are represented by vectors toward the left and positive values toward the right.

Considering again, the flux in coil B increases but in the opposite direction, while in coil A the flux decreases. Complete the parallelogram and draw the diagonal for the resultant as before. The resultant will be found to have moved on past the horizontal position of the vector of coil A. As the flux in coil B increases the flux in coil A decreases and the resultant vector moves on until it equals and coincides with the vector of coil B, reaching again the vertical position but in the negative direction. The flux in coil A now increases in the opposite direction and the resultant vector R moves on until it equals and coincides with the vector of the flux in coil A. The flux in coil B now begins

to increase in the first direction and the flux in coil A decreases. When the flux in coil A reaches zero the flux in coil B is maximum and the resultant R has reached the point of starting. Hence for each cycle of the two fluxes in quadrature there is one revolution of the flux vector R. If the current varies according to a sine wave the relation between the two instantaneous values of the corresponding flux is such as to always give the same magnitude to the resultant vector representing the resultant flux.

Art.2. INTERACTION OF A MAGNETIC FIELD UPON ITS INDUCED CURRENT IN THE CONDUCTOR.

About 1824, Gambey discovered that a magnetic needle when set in motion, came to rest sooner if the bottom of the box was made of copper or some good conductor than if it were made of wood or some poor conductor.* Arago demonstrated before the Academie de Science, in 1824, by several experiments, the same phenomenon. He suspended inside copper and inside wood rings a magnetic needle; this was pushed aside from its stationary position to an angle of 45° and then allowed to vibrate and the number of oscillations counted until the needle came to rest. He found that in the wood ring there were 144 oscillations, in the thin copper ring there were 66, in the heavy copper ring there were only 33. This showed the damping action caused by the copper ring. H

*"Polyphase Electric Currents and Alternating Current Machinery"
By S. P. Thompson.

decided that there was a force present which existed only when there was motion and he called this "Magnetism of Rotation."

In 1825, Babbage and Herschel, showed that if a magnet placed under a copper disk which is pivoted and able to move freely, upon being revolved caused the copper disk to revolve also and with a speed somewhat proportional to the speed of the magnet.* They also noticed that if several radial slits were cut in the disk the tendency to rotate was greatly decreased.

It was not until 1831, that a theory was founded which satisfactorily explained these phenomena. At this time Faraday showed that when a disk was revolved in a magnetic field there were currents set up in the disk and that these currents, called eddy currents, set up a field of force which opposed the field of the magnet and hence caused the disk to tend to come to rest, according to Lenz law.** He also showed that if a copper disk was placed edgewise between the poles of a strong magnet, and a copper brush was placed on the edge and one on the shaft, a current would flow through the wire connecting the brushes, when the disk is revolved. Therefore, a conductor moving so as to cut the lines of force of any field will have induced in it an E.M.F. which will cause a current to flow, which current in turn has a field of

* Thompson Ibid.

** Electricity and Magnetism. By S.P. Thompson. Page 466.

force surrounding it which tends to repel the first field and in turn is repelled by it; hence, the motion is opposed as stated in Lenz law. A copper disk pivoted, and centered over a revolving magnet, rotates in the same direction as the magnet. This is explained as follows; when the magnet revolves the lines of force are also revolved and cut the disk thereby setting up eddy currents in the disk, these eddy currents in turn set up a field of force which opposes the field due to the magnet. Since the magnet is revolving and

the field caused by the eddy currents is reacting against it and cannot stop it the disk must necessarily revolve with almost the same speed.

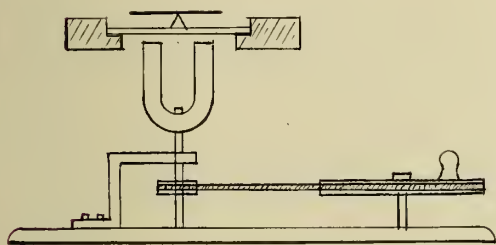


Fig. 5.

The revolving magnet produces nothing more nor less than a revolving magnetic field. Hence, if the revolving magnet is replaced by a revolving field the same effect will be produced. The revolving field is stronger and therefore considerable torque can be produced, as in the induction motor.

If a copper cylinder is now placed in the rotating field eddy currents are set up in it which cause it to rotate in the same manner as the disk. By cutting slots in the cylinder it is made equivalent to a "squirrel cage" so called, in which the bars serve as conductors for the eddy currents and

and the field set up by them is stronger and therefore the torque is greater.

Art.7. EARLY TYPES OF INDUCTION MOTORS.

The first induction motor was made by Walter Baily, in 1879.* There were four electromagnets set horizontally and close together. Over these and close to them was pivoted a copper disk. By means of a commutator, which was turned by hand, a current was sent from the batteries and alternately reversed in the coils of the magnets, which were connected so that the diagonal coils were in series with each other. By this means the lines of force were cut by the disk and eddy currents were induced in it, hence it rotated. If the direction of the current in one coil is reversed the direction of rotation is reversed and if the relative time of reversals of the current in the two circuits is changed the direction of rotation is also changed.

In 1885, Professor Ferraris made the first motor which had a rotating field due to two alternating currents which differed in phase by 90° . He used two pairs of electromagnets connected in series around which was a yoke made of iron wire. The difference of phase was made by placing in one circuit a large non-inductive resistance, a, in fig.6, and in the other circuit a large inductive resistance, b, in fig. 6, and connecting both circuits to a single phase supply. A closed copper cylinder pivoted between the magnets

*Thompson. Ibid.

was made to rotate and the direction of rotation was changed by reversing the relative relations of of the split single phase current, as it enters the motor practically as a two

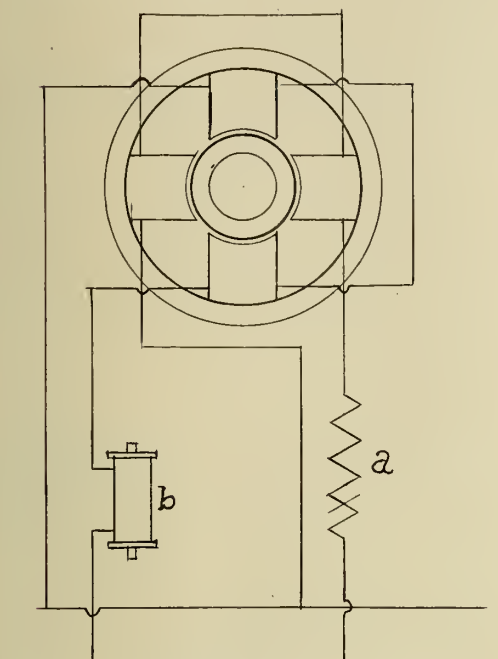


Fig 6.

mechanical rotation of the rotor the slip, and also stated that the current in the rotor was proportional to the slip, and that the power of the motor is proportional to the slip and the speed of the rotor.

The next step was taken in 1887, when Nikola Tesla developed his two phase induction motor, the rotating field being more nearly uniform. A ring of iron was divided into four sections and around this in each section was wrapped copper wire. These coils were then connected in series and to the slip rings of the generator. The armature of the generator had two coils placed at right angles to each other.

phase current in quadrature. He later made a large motor the windings of the magnets being circular and entirely surrounding the rotor. These magnets were divided into two pairs and the pairs were placed at right angles to each other. Ferraris called the difference in angular velocity of the rotating field and the

Therefore, the E.M.F. of the two coils of the generator would be in quadrature. When the generator was delivering a two-phase current a rotating field was consequently set up in the field of the ring forming the stator, and the iron disk forming the rotor was caused to rotate by it.

CHAPTER II.

THEORY AND PRINCIPLES.

Art.1. GENERAL PRINCIPLES UNDERLYING THE ACTION OF THE INDUCTION MOTOR.

When the current is flowing in the stator of an induction motor, the rotor being at rest, a high E.M.F. is induced in the short-circuited windings of the rotor, which causes large currents to flow in these rotor windings. These currents set up fields of force which oppose the revolving field. Since the rotor is free to turn it tends to follow the revolving field. If the rotor were mechanically driven at the same speed as the revolving field, that is, at synchronous speed, the lines of force would not be cut by its conductors and therefore no counter E.M.F. would be induced in the windings. Hence, the magnitude of the induced E.M.F. in rotor windings depends on the relative difference of speed between the revolving field and the rotor. Now, as the rotor speeds up, due to the induced rotor currents, the relative difference of speed is decreased and the induced rotor currents are therefore decreased. The difference of speed, or the slip, will be such that the current induced in the rotor will be just large enough to produce a torque sufficient to overcome the mechanical resistance or work. If a load is belted to the shaft of the rotor the slip will increase thus increasing the induced current and in turn increasing the torque to

the amount necessary to carry the load.

The speed of an induction motor can be varied in one of three ways, viz:*

- (a) Rheostatic control in the secondary or rotor.
- (b) Varying the impressed voltage.
- (c) Altering the number of poles.

The first is probably the most expensive yet the most desirable for all ranges of speed. The windings of the rotor, similar to a three phase star, are brought to three collecting rings and the current is lead through a variable non-inductive resistance with controller, where the energy is dissipated in heating the resistance. For a certain load there is a certain current required in the rotor windings to produce the required torque. If in the external circuit of these windings there is put a non-inductive resistance which will consume some of the energy of the current and dissipated it in heat, then the current, to carry the fixed load, must be increased by the amount dissipated in heating the resistance. To increase the current in the rotor windings the slip must be increased and therefore the speed of the rotor must be decreased. Hence, the introduction of resistance tends to reduce the speed of the rotor. The introduction of the resistance also tends to decrease the angle of lag between the impressed H.L.F. and current which raises the power factor of the motor.

*"Alternating Current Systems" by H.S.Meyer. London Engineering Vol.71, April 19, 1901, Page 405.

The second method requires a transformer or compensator having a variable ratio, which is placed in the external circuit thus raising and lowering the impressed voltage. These accessories are very inefficient, therefore this method is not a practical one.

The third method is the cheapest as well as the most efficient but much more complicated in its mechanical requirements. It can only be used where the speed is to be varied by a series of steps in the ratio of two to one or some multiple of this. For every rotation of revolving field, if it were a bipolar machine, there would be one revolution of the rotor minus the slip. Thus, a bipolar machine running on 60 cycles and with 5% slip would have a speed of 3420, which would be excessive. By placing four coils in series in each leg, so connected that they are of alternate polarity, it will require two cycles for any N pole to move one complete revolution around the stator. Hence by this method the speed of the rotor is just halved. If this division of the poles is carried still farther, making eight poles the speed will be one quarter of the speed of the bipolar field; etc.

Synchronous speed is always understood to be the speed without slip and is therefore, the speed corresponding to the frequency.

Multi-Speed Induction Motor Changes:

Poles.	Frequency.	R.P.M.	Examples.
2.	60	3600	
4.	60	1800	Thesis, 2 H.P. Westinghouse Motor.
8.	60	900	E.E. Lab. 40 H.P. " "
16.	60	450	
72.	60	225	

Art.2. RELATION OF AN INDUCTION MOTOR TO AN ALTERNATING CURRENT TRANSFORMER.

If the rotor of an induction motor is blocked, the rotating field will induce in the short-circuited windings an alternating current. Around each conductor of the rotor there will be a field of force, which field, through its counter E.M.F., will oppose the primary field just the same as the primary field of a single-phase transformer is affected by the current which would be induced in the short-secondary. If these rotor windings were not all short-circuited but were open or closed through an external resistance, the case would be similar to a transformer on open-circuited secondary or with loaded secondary, respectively.* In the former case the current flowing in the stator would be the magnetizing current and that due to hysteresis and eddy current losses and therefore a constant quantity for a given frequency,

* "The Polyphase Induction Motor" by R.I. Marshon. E.W. & E.

and the copper losses would be very small. In the second case, as the external resistance is increased the current flowing is increased and therefore the copper losses are increased and the total losses at any load is the sum of the losses on open circuit and the copper losses due to the resistance.

When the rotor coils are short circuited a heavy induced current flows through them and corresponding energy must be taken from the line by the stator in addition to the magnetizing current. The slip in the induction motor is analogous to the drop in voltage in the alternating current transformer.

Art. 3. RELATION OF THE INDUCTION MOTOR TO A DIRECT-CURRENT MOTOR.

Upon starting a direct-current motor there is a heavy rush of current in the armature. This is generally dissipated in the usual starting box resistances which are put in the armature external circuit. There is a similar result in starting an induction motor, and it is taken care of in a like manner if there is external resistance in the rotor circuit. In the armature of the shunt motor there is a counter E.M.F. generated due to the conductors cutting the lines of force of the shunt field. The mechanical work of the motor is against this counter E.M.F. In an induction motor there likewise is a similar action. A counter E.M.F. is generated in the primary windings due to the induced currents in the revolving

secondary windings. This counter E.L.F. is similar to the counter E.L.F. of the shunt motor,- so that in both motors the speed falls off as the load is increased and no other change of operating conditions is made*.

* Mershon, Ibid.

CHAPTER III.

CLASSIFICATION.*

Rotary induction apparatus which consists of primary and secondary windings rotating with respect to each other, can be divided as follows:

- (a) Induction Motors.
- (b) Induction Generators.
- (c) Frequency Changers.
- (d) Rotary Phase Transformers.

The subject of this thesis comes under (a) Induction Motors. This class can further be divided into,

- (1) Induction motors with variable resistance in rotor.
- (2) Induction motors with short-circuited rotor windings, or "squirrel cage" rotors.

The motor on which the thesis tests were made is in the second class having a short-circuited or squirrel cage rotor.

A further classification is usually made into motors of variable and constant speed, and therefore corresponding to the above classification.

* Standardization Rules. American Institute of Electrical Engineers. Volume XVI. 1899.

CHAPTER IV.

CONSTRUCTION.

Manufacturers type	C.
Serial number	135698
Type of machine	Two-phase
Number of poles	4
Capacity in H.P.	2.
Speed R.P.M. No load	1800
Speed R.P.M. Full load	1700
Volts, normal.	110
Current, Full load	10 amperes
Current, No load	5.5 amperes

ROTOR.

Peripheral velocity - feet per second	70
Diameter over all	8 inches
Diameter of core, internal	6.5 inches
Length over all	6.75 inches
Width of slot, at bottom	$3/8$ inch
Width of slot, at surface	$1/16$ inch
Depth of slot	$3/8$ inch
Insulation	Press Board
Width of tooth, at root	$5/16$ inch
Width of tooth, at surface	$9/16$ inch
Size of conductor	$5/16 \times 5/16$

Number of conductors per slot	1
Air gap	.031 inch
Length of tooth	4 11/16 inches

STATOR.

Length of core	4 3/4 inches
Number of slots	72
Depth of slots	1 inch.
Width of slots	1/8 inch.

Insulation	Tape and Shellac
Width of tooth	1/8 inch.
Polar embrace	360°
Length of polar arc	90°
Coils per slot	1
Coils per pole	9
Coils in series	9

Resistance	Coil $A_1 - A_2$	2.63 ohms
	" $A_3 - A_4$	2.59 "
	" $A_5 - A_6$	2.62 "
	" $A_7 - A_8$	3.55 "
	" $B_1 - B_2$	2.10 "
	" $B_3 - B_4$	2.82 "
	" $B_5 - B_6$	2.55 "
	" $B_7 - B_8$	2.62 "

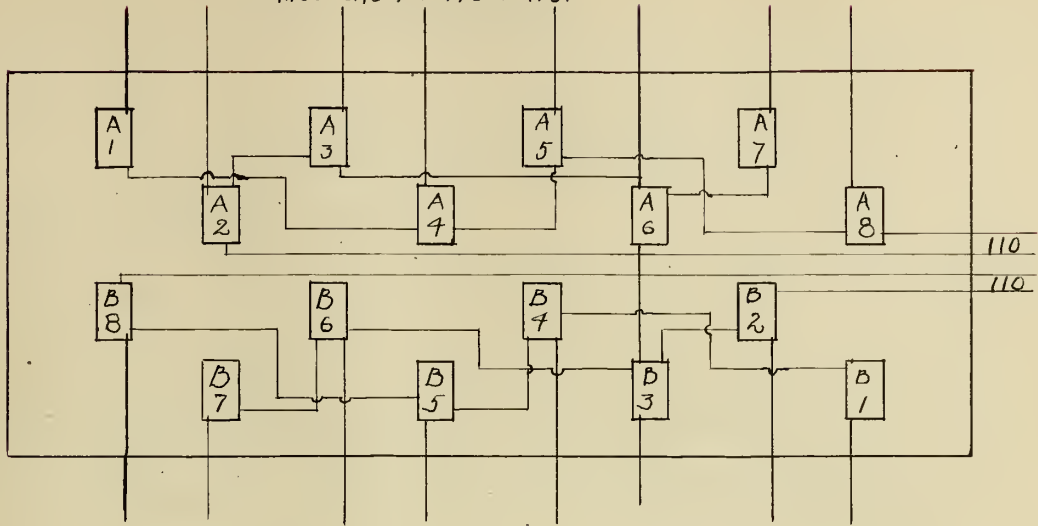
The above measurements are taken from the Westinghouse Two-Phase 2 H.P. Induction Motor upon which the experiments

for this thesis were made.

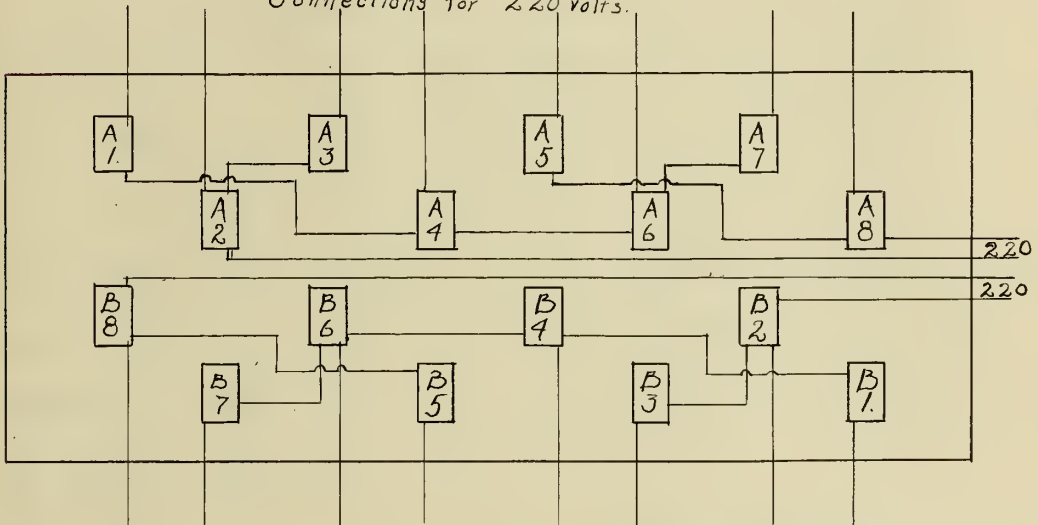
The stator winding is distributed and each pole consists of nine (9) coils which are connected in series. The terminals are brought to a switchboard on top of the machine where connections can be made for operating at 110, 220, or 440 volts. A diagram is given on Plate Number 1, showing these connections.

The bearings are in the casings which close the sides of the stator. They are self oiling. The rotor is well balanced and turns very freely in the bearings. It has been found from three or four experiments, that it requires, on the average, eleven minutes for the rotor to come to standstill after the current is shut off, the motor running light at that instant.

Connections for 110 volts.



Connections for 220 volts.



Connections for 440 volts.

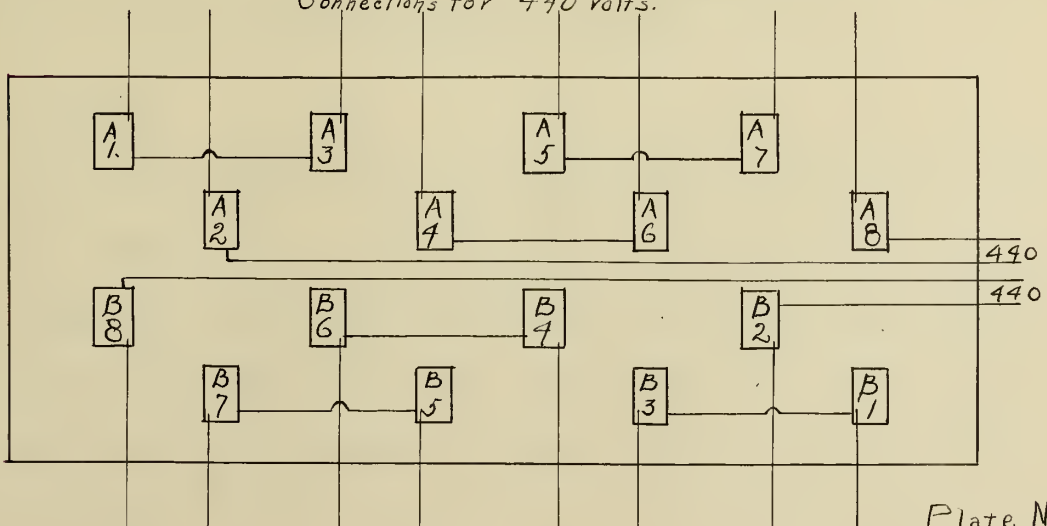


Plate No. 1.

Wiring Diagram of Machine Switchboard.

CHAPTER V.

PERFORMANCE AND TESTING.

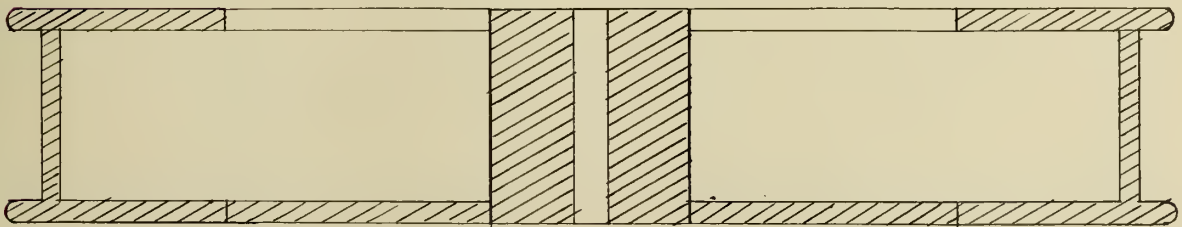
Art.1. METHODS EMPLOYED.

The motor was fastened securely to a frame foundation. On one end of the shaft was a brake wheel shown on Plate 2 . It was so arranged that water could be applied to the rim to dissipate the heat. Suspended from a spring balance was a one quarter inch hemp rope, so placed as to be tangent to the brake wheel rim. The rope made one turn around the brake wheel and passed down and around a smooth pulley and then up to a second spring balance as shown in Plate 3. The difference in readings of the two balances gives the pull acting at a radius equal to the radius of the pulley plus the diameter of the rope. The output in watts is given from the following formulae,

$$\frac{2\pi \times 746 \times \text{R.P.L.} \times (T_1 - T_2) \times \text{effective radius in feet}}{33,000} =$$

Output Watts.

Speed was measured by a Weston Magneto Speed Indicator. This was belted to the shaft at the opposite end from the brake wheel. It was calibrated ^{by} means of speed taken with a speed counter and timed by the laboratory stop watch. The deflection of the voltmeter is noted and the speed for any other voltage is proportional to the observed speed and voltage, as shown by frequent calibrations.



Brake Wheel.



Rope Brake.

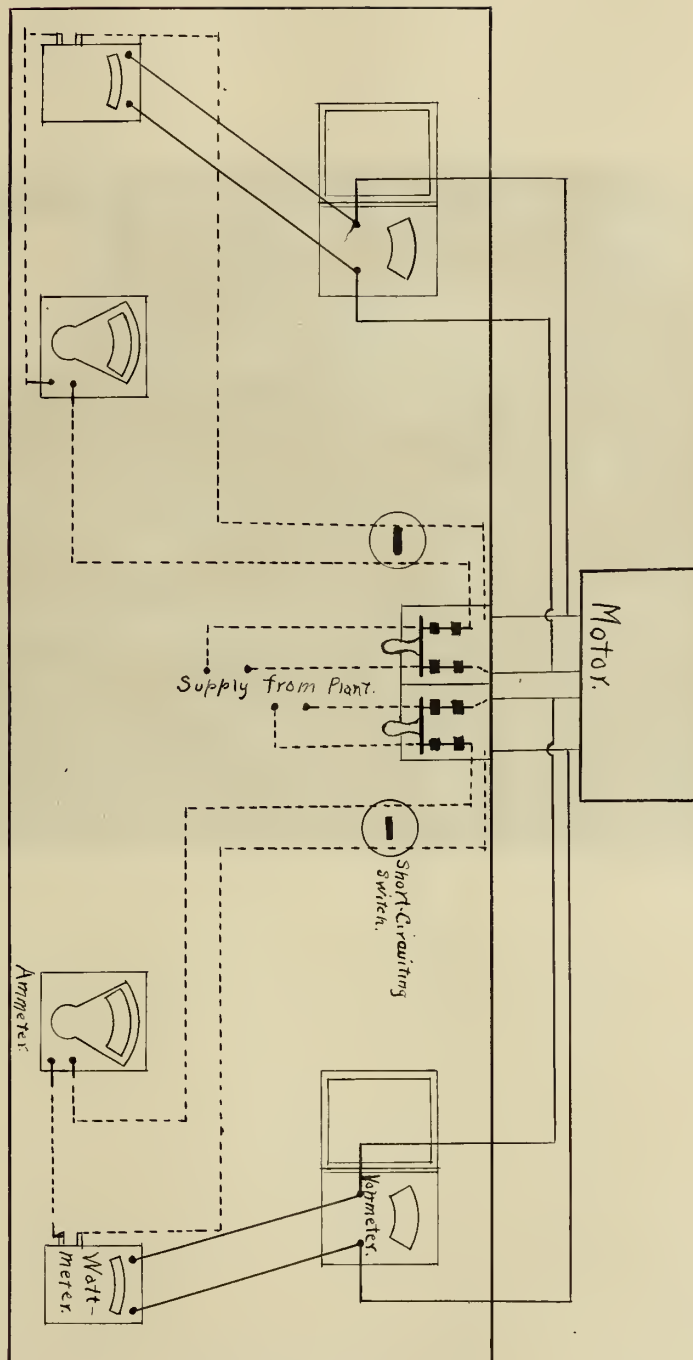
Plate No. 3.

The electrical input was measured by a Weston Wattmeter and Voltmeter and a Thompson Ammeter in each leg. A table was wired permanently and the instruments set on it as shown in Plate 4, and in Plate 5.

The current was taken from the University Plant where it is generated at a voltage of 440. It was transformed down to 110 in two Westinghouse C.D. Transformers. There was a Westinghouse potential regulator attached to the transformers and by this the voltage could be maintained constant.

Art.2. ERRORS AND PRECAUTIONS.

Having started a test on a certain voltage as the new load was added it was necessary to allow it to run a minute or two and so reach a steady value. Errors also might arise from not having the instruments all read at the same time but this was overcome as far as possible by having all readings taken a signal by the person adjusting the load. Before each reading the voltage was observed and kept constant by the potential regulator. All instruments were calibrated by comparison with the Weston Laboratory Standards and the readings corrected before calculations were made therefrom. In all cases single readings alone were taken for each condition of the experiment.



Wiring Diagram of Table.

Plate No. 4.



Plate No. 5.

Arrangement of Instruments.

Art. 3. EFFECT OF VARIABLES UPON THE PERFORMANCE OF THE INDUCTION MOTOR.

The speed is practically independant of the voltage at no load, until the voltage becomes very small when the speed drops off very rapidly. If the motor is loaded the output will vary proportionally to the square of the voltage. This can be shown by the following readings of output and taken at about the same speed, from the calculated results of the experiments performed.

Exp. No.1, Sheet C. Volts 115, Output Watts 1310, Speed 1708

Exp. No.2, Sheet C. Volts 110, Output Watts 1189, Speed 1710

Exp. No.3, Sheet C. Volts 105, Output Watts 1220, Speed 1705

$$115^2 : 1310 :: 110^2 : 1189 :: 105^2 : 1220.$$

Which proportion holds very nearly true, since the speed varies somewhat and personal errors also enter.

Change in frequency varies the speed of the rotating field and the speed of the motor depends on this. The output depends directly on the speed and therefore it depends on the frequency. The frequency in the rotor at starting is very high but as the slip decreases the frequency of the induced current decreases.

This motor requires a starting current of about fifty amperes at 110 volts, found from a number of experiments. The speed curves are shown on Plates 6, 10, 12, for 115, 110, and 105 volts respectively. The lower the voltage the more rapidly the speed drops off, implying therefore, a greater

slip for the same load with a lower voltage. The current being proportional to the slip, should be a steeper curve for lower voltages, as is shown on Plates 7, 11, and 13.

The break-down point of the motor could not be determined, on account of the excessive heating in the stator coils due to the large current flowing at both 110 and 440 volts. The manufacturers of this machine, the Westinghouse Electrical Manufacturing Company, claim,* with regard to this type and make there will be: "No damage if overloaded and stopped for several seconds." Evidently the copper allowance for the stator windings have been made quite small, and the carrying capacity is not sufficient to carry the current as a transformer with a short-circuited secondary and an impressed voltage of 110.

The output in all cases was carried to a maximum and then as the torque was increased the speed fell off so rapidly that the output was smaller. The maximum output for 115 volts was the greatest obtained. The efficiency for this voltage reached a maximum at about full load and held up very well to about 100% overload. The efficiency for 110 volts, and 105 volts, respectively reached a maximum somewhat before full load and dropped off rapidly afterward.

The power factor does not vary much from its main characteristic, with the voltage and is of the same general appearance in all three experiments.

The wattless current increases more rapidly for the
*Circular No. 1029 "Polyphase Induction Motors:" July 1900.

lower voltages.

On Plate 8, the inductive volts drop or $E \cos \phi$ are platted on a true input watts base, they are a maximum at no load and decrease to a minimum and then increase slightly. When platted on ϕ as a base a true cosine wave is formed.

Wattless watts and wattless current platted on true input watts base, Plate 8, increase from a minimum as the input is increased.

On Plate 9, there is platted the equivalent resistance on true watts input base. The equivalent resistance is found by dividing $E \cos \phi$ by the current, or in other words, it is applying Ohms law to the alternating current. It rises from zero to a maximum and then gradually drops off. The other figure on Plate 9, has its base line laid off to represent the impressed voltage, 115 volts. Three cases are taken, observations number 1, 5, and 19 from Experiment No. 1, the values of $E \cos \phi$, and $E \sin \phi$, columns 8 and 9. The triangle of electromotive forces is made in each case and the points C, D, and E were found to lie exactly on a semi-circle constructed on the impressed voltage.

From the foregoing tests the statements of Mr. H. S. Meyer in the London Engineering*, earlier noted, have been more or less verified. He sets forth the following advantages of the induction motor.

1. Possibility of starting under heavy load, which is an absolute necessity in some cases.

*H. S. Meyer. Ibid.

2. The primary circuit serves a double purpose, furnishing both the exciting and load current, thereby doing away with a direct current exciting source.

3. Great simplicity in mechanical construction, more particularly in the revolving parts where frequently, by the use of a "squirrel-cage" winding all current collecting devices are avoided.

4. The voltage of the rotor can be made very low, thus simplifying insulation.

5. The motor can be worked at different speeds.

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 115.

EXPERIMENT No.1. SHEET A.

APRIL 11, 1901.

ORIGINAL DATA. OBSERVED.

Table No.1.

No. Obs.	R.P.M. Weston Vm. #3937	Top Balance 0 to 30.	Bottom Balance 0 to 15.	Voltmeter Weston #2882	Ammeter Thompson #14008	Wattmeter Weston #1505	Voltmeter Weston #2931.	Ammeter Thompson #14010	Wattmeter Weston #1500
	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	102.3	0	0	115.2	5.97	130.	115.5	5.6	50
2.	98.8	4-14	0-10	114.5	6.30	420.	115.0	6.25	310
3.	97.2	7-12	1-1.5	114.0	7.05	542.	114.5	6.85	460
4.	96.2	10-5	1-11.5	113.5	7.80	660	114.0	7.55	590
5.	95.0	12-6	2-4	114.5	8.50	760	115.0	8.15	680
6.	94.2	14-6	2-12.	115.0	9.15	850	115.5	8.70	770
7.	93.8	16-6	3-6.5	115.2	9.90	950	115.8	9.40	870
8.	92.7	18-12	3-13	115.0	10.70	1050	115.4	10.20	970
9.	91.9	20-14	4-8	114.9	11.60	1150	115.0	11.00	1070
10.	90.4	23-3	5-6	114.4	12.40	1250	114.8	11.9	1200
11.	90.0	25-9	6-4	114.7	13.10	1340	115.0	12.5	1270
12.	88.9	27-11	7-0.5	115.3	13.90	1455	115.5	13.4	1380
13.	88.0	29-6	7-8	115.0	15.2	1560	115.2	14.4	1480
14.	88.0	31-8	8-12	115.1	15.2	1640	115.8	14.2	1560
15.	88.0	33-10	9-3	114.8	16.4	1770	115.0	15.6	1700
16.	87.2	35-2	9-13	115.0	17.3	1880	115.0	16.5	1810
17.	86.2	36-5	9-13.5	115.1	18.0	1970	114.8	17.3	1900
18.	84.8	38-1	9-13.5	115.2	19.2	2100	114.1	18.5	2100
19.	82.0	38-4	9-15	115.2	20.3	2240	115.2	19.7	2160
20.	81.5	41-2	9-15.5	115.0	22.0	2400	115.8	21.2	2320
21.	80.0	41-14	10-1	114.9	23.0	2500	115.0	22.2	2420
22.	78.2	43-0	10-1.5	114.7	24.2	2640	115.0	23.3	2560
23.	76.5	44-0	10-1	114.3	26.0	2820	114.8	25.0	2720
24.	74.5	45-6	10-0.5	115.0	27.2	3000	115.0	26.4	2900

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 60 ∞ , 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 115.

EXPERIMENT No. 1. SHEET B.

APRIL 11, 1901.

ORIGINAL DATA. CORRECTED.

Table No. 2.

No. Obs.	R.P.M. Weston Vm. #3937	Top Balance 0 to 30	Bottom Balance 0 to 15	Voltmeter Weston #2882	Ammeter Thompson #14008	Wattmeter Weston #1505	Voltmeter Weston #2931	Ammeter Thompson #14010	Wattmeter Weston #1500
	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	102.3	0	0	115.2	5.81	190	115.5	5.90	50
2.	98.8	4.312	0.125	114.5	6.68	440	115.0	6.55	310
3.	97.2	7.187	0.593	114.0	7.50	563	114.5	7.20	460
4.	96.2	9.750	1.218	113.5	8.26	690	114.0	7.95	590
5.	95.0	11.812	1.750	114.5	9.02	784	115.0	8.55	680
6.	94.2	13.812	2.250	115.0	9.72	874	115.5	9.15	770
7.	93.8	16.000	2.908	115.2	10.51	980	115.8	9.90	870
8.	92.7	18.187	3.312	115.0	11.35	1080	115.4	10.72	970
9.	91.9	20.312	4.000	114.9	12.32	1183	115.0	11.55	1070
10.	90.4	22.625	4.875	114.4	13.18	1283	114.8	12.50	1200
11.	90.0	25.000	5.750	114.7	13.90	1378	115.0	13.12	1270
12.	88.9	27.125	6.582	115.3	14.75	1493	115.5	14.10	1380
13.	88.0	29.375	7.000	115.0	16.05	1600	115.2	15.15	1480
14.	88.0	32.375	8.250	115.1	16.80	1682	115.4	15.85	1560
15.	88.0	34.500	8.687	114.8	18.05	1810	115.0	17.20	1700
16.	87.2	36.000	8.812	115.0	19.15	1928	115.3	18.20	1810
17.	86.2	37.187	8.812	115.1	19.80	2020	115.0	19.05	1900
18.	84.8	38.937	8.845	115.2	20.80	2158	115.2	20.00	2100
19.	82.0	39.125	8.937	115.2	22.20	2292	115.8	22.40	2160
20.	81.5	42.000	8.970	115.0	24.20	2458	115.0	23.20	2320
21.	80.0	42.750	9.062	114.4	25.40	2560	115.0	24.30	2420
22.	78.2	43.875	9.093	114.7	26.80	2700	114.8	26.00	2560
23.	76.5	45.875	9.062	114.3	28.80	2890	114.1	27.40	2720
24.	74.5	46.250	9.031	115.0	30.70	3070	115.0	29.10	2900

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 115.

EXPERIMENT No. 1. SHEET C.

APRIL 11, 1901.

CALCULATED DATA.

Table No. 3.

No. Obs.	R.P.M.	Pull in. pounds.	Torque.	Total Watts Output.	Total Watts Input.	True Efficiency
	1.	2.	3.	4.	5.	6.
1.	1850	0	0.	0	190	0
2.	1778	4.187	2.000	495	750	66.0
3.	1758	6.536	3.28	765	1023	75.6
4.	1740	8.536	4.07	990	1280	77.4
5.	1720	10.062	4.80	1152	1464	78.8
6.	1702	11.562	5.52	1310	1644	79.8
7.	1698	13.092	6.54	1480	1850	80.1
8.	1675	14.875	7.10	1668	2050	81.5
9.	1660	16.312	7.78	1808	2253	80.4
10.	1635	18.187	8.74	1980	2480	80.0
11.	1628	19.250	9.18	2088	2648	79.0
12.	1609	20.543	9.78	2200	2873	76.8
13.	1590	22.375	10.67	2368	3080	77.0
14.	1590	24.125	11.51	2560	3242	79.0
15.	1590	25.812	12.64	2740	3510	77.8
16.	1575	27.187	12.95	2850	3738	76.4
17.	1558	28.375	13.54	2940	3920	75.0
18.	1535	30.092	14.35	3075	4258	72.0
19.	1483	30.187	14.40	3090	4452	69.3
20.	1472	32.031	15.30	3145	4778	66.0
21.	1446	33.687	16.08	3220	4980	64.7
22.	1412	34.786	16.57	3278	5260	62.3
23.	1382	36.812	17.58	3390	5610	60.3
24.	1348	37.218	17.76	3350	5970	56.1

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 60 ∞ , 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 115.

EXPERIMENT No. 1. SHEET I.

APRIL 11, 1901.

CALCULATED DATA.

Table No. 4.

No. Obs.	Apparent Watts.	Power Factor	ϕ	$\sin \phi$	$I \sin \phi$	$I \cos \phi$	Wattless Watts.	$E \cos \phi$	$E \sin \phi$	Equivalent Resistance
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
1.	670	.209	77° 4'	.978	5.68	1.68	655	27.1	112.5	4.15
2.	767	.567	55° 33'	.823	5.50	3.79	631	65.0	94.2	9.74
3.	856	.650	49° 33'	.759	5.68	4.87	656	74.2	86.6	9.88
4.	938	.736	42° 36'	.676	5.57	6.07	635	83.6	76.7	10.12
5.	1034	.755	40° 58'	.655	5.90	6.80	677	86.6	75.0	9.62
6.	1117	.782	38° 33'	.623	6.06	7.60	695	90.0	71.7	9.28
7.	1212	.809	36° 0'	.587	6.17	8.52	712	93.2	67.7	8.86
8.	1304	.829	34° 0'	.559	6.34	9.42	728	95.3	64.3	8.40
9.	1416	.838	33° 4'	.545	6.72	10.32	795	96.4	62.6	7.82
10.	1510	.850	31° 47'	.526	6.94	11.20	795	97.5	60.3	7.40
11.	1593	.862	30° 27'	.506	7.04	11.80	822	99.0	58.1	7.12
12.	1720	.868	29° 46'	.496	7.32	12.80	854	100.2	57.2	6.80
13.	1847	.869	29° 39'	.494	7.93	13.90	913	100.0	56.8	6.24
14.	1932	.870	29° 32'	.492	8.25	14.61	952	100.3	56.6	5.98
15.	2078	.872	29° 18'	.489	8.84	15.70	1000	100.2	56.3	5.56
16.	2200	.876	28° 50'	.482	9.23	16.75	1057	100.8	55.4	5.26
17.	2280	.886	27° 37'	.463	9.17	17.52	1052	102.0	53.4	5.15
18.	2402	.888	27° 22'	.459	9.55	18.45	1100	102.3	52.8	4.92
19.	2580	.890	27° 7'	.465	10.04	19.75	1171	102.5	52.4	4.63
20.	2775	.887	27° 30'	.461	11.14	21.44	1278	102.0	53.0	4.22
21.	2915	.883	27° 59'	.469	11.90	22.41	1372	101.5	53.8	4.00
22.	3070	.880	28° 21'	.474	12.70	23.60	1452	100.9	54.3	3.78
23.	3300	.875	28° 58'	.484	13.91	25.20	1595	100.0	55.4	3.48
24.	3530	.870	29° 32'	.492	15.08	26.75	1732	100.2	56.6	3.27

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 110.

EXPERIMENT No. 2. SHEET A.

APRIL 13, 1901.

ORIGINAL DATA. OBSERVED.

Table No. 5.

No. Obs.	R.P.M. Weston Vm #3937	Top Balance 0 to 30	Bottom Balance 0 to 15.	Voltmeter Weston #2882	Ammeter Thompson #14008	Wattmeter Weston #1505.	Voltmeter Weston #2931	Ammeter Thompson #14010	Wattmeter Weston #1500
	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	106.8	0	0	110.0	5.2	122	110.0	5.35	40
2.	103.9	1-12	0-9.5	110.0	5.6	270	111.0	5.55	180
3.	103.9	3-11	0-13.	110.0	5.9	370	110.0	5.85	280
4.	103.3	5-10	1-8.5	109.8	6.33	450	110.5	6.20	360
5.	101.5	7-0	1-6.5	109.5	7.00	530	110.4	6.70	460
6.	99.2	9-6	1-13.	109.5	7.75	648	110.0	7.40	580
7.	97.9	11-8	2-4.5	109.8	8.50	758	110.5	8.05	670
8.	96.2	13-12	3-1.5	110.0	9.20	840	111.0	8.75	780
9.	95.1	16-2	3-10	110.0	10.20	950	110.5	9.60	880
10.	94.0	18-2	4-2	109.8	11.10	1050	110.2	10.30	980
11.	92.0	21-0	5-9.5	110.0	11.30	1150	110.5	10.30	1080
12.	90.0	23-2	6-3.5	109.8	12.60	1270	110.2	11.40	1200
13.	88.5	25-7	6-12	110.0	13.60	1380	110.8	12.60	1310
14.	89.9	26-11	6-15.5	110.0	14.40	1460	110.4	13.30	1400
15.	89.0	28-3	7-1.5	109.8	15.00	1550	110.2	14.00	1460
16.	87.5	30-3	7-4.5	109.7	16.20	1680	110.1	15.30	1600
17.	87.2	31-8	7-6	110.2	16.80	1760	110.8	16.00	1700
18.	85.0	33-13	7-7.5	110.0	16.80	1960	110.5	18.00	1900
19.	85.0	32-6	6-12	110.0	19.80	2070	110.2	19.20	2000
20.	82.1	34-14	6-13.5	109.7	21.20	2220	110.0	20.70	2180
21.	80.9	36-2	6-14	109.5	22.30	2350	110.0	21.70	2260
22.	78.6	37-8	6-13.5	110.0	23.80	2500	110.5	23.00	2400
23.	76.0	38-8	6-13.5	109.8	25.20	2620	110.0	24.30	2560
24.	75.0	39-7	6-13.0	109.4	26.30	2740	110.0	25.50	2660
25.	70.5	41-7	6-13.5	110.2	27.70	2920	110.5	27.00	2860

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 110.

EXPERIMENT No.2. SHEET B.

APRIL 13, 1901.

ORIGINAL DATA. CORRECTED.

Table No. 6.

No. Obs	R.P.M. Weston V.M. #3937	Top Balance 0 to 30	Bottom Balance 0 to 15.	Voltmeter Weston #2882	Ammeter Thompson #14008	Wattmeter Weston #1505	Voltmeter Weston #2931	Ammeter Thompson #14010	Wattmeter Weston #1500
	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	106.8	0	0	110.0	5.53	132	110.0	5.62	40
2.	103.9	2.625	0.093	110.0	5.96	282	111.0	5.95	180
3.	103.9	4.562	0.312	110.0	6.25	390	110.0	6.15	280
4.	103.3	6.500	1.031	109.8	6.70	470	110.5	6.50	360
5.	101.5	7.875	0.908	109.5	7.45	550	110.4	7.05	460
6.	99.2	10.250	1.312	109.4	8.24	670	110.0	7.80	580
7.	97.9	12.375	1.782	109.8	9.03	780	110.5	8.75	670
8.	86.2	14.625	2.593	110.0	9.78	868	111.0	9.20	780
9.	95.1	17.000	3.125	110.0	10.85	980	110.5	10.10	880
10.	94.0	19.000	3.625	109.8	11.80	1080	110.2	10.82	980
11.	92.0	21.875	5.093	110.0	12.30	1184	110.5	11.50	1080
12.	90.0	24.000	5.697	109.8	14.00	1310	110.2	12.60	1200
13.	88.5	26.125	6.250	110.0	14.90	1420	110.8	14.00	1310
14.	89.9	27.562	6.468	110.0	15.80	1500	110.4	14.70	1400
15.	89.0	29.062	6.593	109.8	16.50	1590	110.2	15.40	1460
16.	87.5	31.062	6.783	109.7	17.80	1720	110.1	16.90	1600
17.	87.2	32.375	6.875	110.2	18.40	1802	110.8	17.60	1700
18.	85.0	34.687	6.970	110.0	20.70	2004	110.5	19.80	1900
19.	85.0	33.250	6.250	110.0	21.80	2120	110.2	20.90	2000
20.	82.1	35.750	6.394	109.7	23.30	2272	110.0	22.80	2180
21.	80.9	37.062	6.375	109.5	24.50	2402	110.0	23.90	2260
22.	78.6	38.375	6.394	110.0	26.20	2560	110.5	25.30	2400
23.	76.0	39.375	6.394	109.8	27.70	2680	110.0	26.70	2560
24.	75.0	40.312	6.375	109.4	28.90	2870	110.0	28.00	2660
25.	70.5	42.312	6.394	110.2	30.70	2990	110.5	29.70	2860

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 110.

EXPERIMENT No.2. SHEET C.

APRIL 18, 1901.

CALCULATED DATA.

Table No. 7.

No. Obs.	R.P.M.	Pull in Pounds.	Torque	True Watts Output.	Total True Watts Input	True Efficiency
	1.	2.	3.	4.	5.	6.
1.	1830	0	0	0	172	0
2.	1780	2.532	1.260	300	462	65.0
3.	1780	4.250	2.150	505	670	75.4
4.	1770	5.458	2.560	642	830	77.4
5.	1740	6.968	3.338	808	1010	80.0
6.	1725	8.885	4.290	1025	1250	81.2
7.	1710	10.425	5.070	1189	1450	82.6
8.	1680	12.031	5.240	1345	1648	81.8
9.	1650	13.675	6.520	1522	1860	81.0
10.	1612	15.375	7.340	1650	2060	80.3
11.	1576	16.782	8.020	1760	2264	77.8
12.	1542	18.283	8.720	1880	2510	75.0
13.	1516	19.875	9.490	2002	2730	73.5
14.	1490	21.093	10.05	2095	2900	72.3
15.	1481	22.485	10.72	2220	3050	72.8
16.	1458	24.483	11.58	2360	3320	71.2
17.	1450	25.500	12.18	2468	3502	70.5
18.	1414	27.720	13.22	2620	3904	67.2
19.	1414	28.000	13.35	2632	4120	64.0
20.	1366	28.475	13.58	2680	4452	60.2
21.	1347	30.687	14.62	2760	4662	59.0
22.	1308	32.031	15.28	2800	4960	56.5
23.	1264	33.431	15.75	2780	5240	53.0
24.	1248	34.000	16.22	2820	5500	51.3
25.	1172	35.968	17.15	2800	5850	48.0

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 110.

EXPERIMENT No. 2. SHEET D.

APRIL 18, 1901.

CALCULATED DATA.

Table No. 8.

No. Obs.	Apparent Watts.	Power Factor.	ϕ	$\sin \phi$	$I \sin \phi$	$I \cos \phi$
	1.	2.	3.	4.	5.	6.
1.	607	21.8	77°36'	97.5	5.43	1.22
2.	657	43.0	64°29'	90.2	5.36	2.56
3.	688	56.8	55°37'	82.2	5.14	3.54
4.	737	63.8	50°39'	76.9	5.14	4.27
5.	817	67.3	47°18'	73.9	5.50	5.02
6.	903	74.2	42°5'	67.0	5.52	6.10
7.	993	78.6	38°11'	61.8	5.58	7.10
8.	1075	80.8	36°5'	58.8	5.75	7.92
9.	1193	82.1	34°48'	57.0	6.18	8.91
10.	1295	83.6	33°16'	54.8	6.48	9.89
11.	1375	86.0	30°41'	51.0	6.33	10.65
12.	1510	86.8	29°46'	49.6	6.86	11.98
13.	1640	86.7	29°53'	49.8	7.42	12.90
14.	1738	86.5	30°7'	50.1	7.91	13.68
15.	1830	87.0	29°32'	49.2	8.11	14.35
16.	1955	88.0	28°21'	47.4	8.45	15.65
18.	2030	88.7	27°30'	46.1	8.48	16.30
18.	2278	88.2	28°6'	47.1	9.75	18.25
19.	2415	88.0	28°21'	47.4	10.38	19.45
20.	2555	87.8	28°35'	47.8	11.11	20.42
21.	2580	87.5	28°57'	48.4	11.82	21.40
22.	2982	87.1	29°25'	49.1	12.85	22.80
23.	3045	86.9	29°39'	49.4	13.68	24.00
24.	3168	86.0	30°41'	51.0	14.72	24.85
25.	3350	85.8	30°54'	51.3	15.60	26.02

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 105.

EXPERIMENT No. 2. SHEET A.

APRIL 25, 1901.

ORIGINAL DATA. OBSERVED.

Table No. 9.

No. Obs.	R.P.M. Weston Vm. #3937	Top Balance 0 to 30	Bottom Balance 0 to 15	Voltmeter Weston #2882	Ammeter Thompson #14008	Wattmeter Weston #1505	Voltmeter Weston #2931	Ammeter Thompson #14010	Wattmeter Weston #1500
	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	103.0	0	0	105.0	7.98	100	105.6	8.15	30
2.	102.0	1-6	1-8	104.5	8.37	250	105.2	8.34	160
3.	101.5	4-11	1-15	105.1	6.10	400	106.0	6.00	340
4.	101.0	7-2	2-7.5	105.0	6.80	510	105.5	6.60	440
5.	100.0	8-12	3-7.5	105.0	7.35	580	105.8	7.10	510
6.	99.0	11-0	3-7.5	104.7	8.20	700	105.0	7.85	620
7.	97.9	13-0	3-14	105.0	8.90	800	105.5	8.55	730
8.	96.1	15-4	4-6	105.0	10.00	900	105.5	9.50	850
9.	95.2	18-4	5-7.5	105.0	11.10	1020	105.5	10.40	960
10.	94.0	20-4	5-13	105.2	11.50	1120	105.8	11.50	1060
11.	93.0	21-11	6-4	105.0	12.7	1210	105.5	12.10	1120
12.	91.7	24-7	6-15.5	105.3	14.0	1340	105.7	13.60	1300
13.	90.0	26-12	7-5	105.2	15.0	1500	105.8	14.20	1450
14.	88.4	28-8	7-8	105.0	16.1	1600	105.3	15.30	1550
15.	84.0	31-0	7-6	105.0	19.0	1870	105.3	18.30	1860
16.	81.2	32-4	7-1	105.0	20.0	2000	105.3	19.30	1960
17.	80.0	33-6	7-1.5	104.5	21.0	2080	105.0	20.40	2040
18.	77.8	34-6	7-4.5	104.2	22.0	2180	105.0	21.40	2130
19.	76.0	35-12	7-6	105.0	23.0	2320	105.4	22.60	2280
20.	71.5	37-12	7-7.5	104.4	26.3	2620	104.8	25.80	2400
22.	68.2	39-0	7-7	105.0	28.0	2780	105.0	27.20	2740
22.	62.0	40-10	8-10	103.0	30.5	2950	105.0	30.00	2960

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 60 ∞ , 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 105.

EXPERIMENT No.3. SHEET B.

APRIL 25, 1901.

ORIGINAL DATA. CORRECTED.

Table No. 10.

No. Obs.	R.P.M. Weston Vmp. #3937	Top Balance 0 to 30	Bottom Balance 0 to 15	Voltmeter Weston #2882	Ammeter Thompson #14008	Wattmeter Weston #1505	Voltmeter Weston #2931	Ammeter Thompson #14010	Wattmeter Weston #1500
	1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	103.0	0	0	105.0	5.30	105	105.6	5.40	30
2.	102.0	2.250	0	104.5	5.70	268	105.2	5.62	160
3.	101.5	5.562	0.437	105.1	6.48	420	106.0	6.30	340
4.	101.0	8.000	0.970	105.0	7.22	530	105.5	6.95	440
5.	100.0	9.625	1.593	105.0	7.80	600	105.8	7.47	510
6.	99.0	11.875	1.970	104.7	8.70	724	105.0	8.23	620
7.	97.9	13.875	2.375	105.0	9.45	826	105.5	9.00	730
8.	96.1	16.125	2.875	105.0	10.62	930	105.5	10.05	850
9.	95.2	19.125	3.782	105.0	11.80	1050	105.5	10.94	960
10.	94.0	21.125	4.312	105.2	12.24	1154	105.8	12.08	1060
11.	93.0	22.562	4.782	105.0	13.46	1248	105.5	12.70	1120
12.	91.7	25.312	5.468	105.3	14.80	1378	105.7	14.30	1300
13.	90.0	27.625	5.850	105.2	16.42	1540	105.8	15.70	1450
14.	88.4	29.575	6.000	105.0	17.70	1642	105.3	16.90	1550
15.	84.0	31.875	5.875	105.0	20.90	1930	105.3	20.10	1860
16.	81.2	33.125	5.562	105.0	22.80	2048	105.3	21.25	1960
17.	80.0	34.250	5.893	104.5	23.10	2128	105.0	22.42	2040
18.	77.8	35.250	5.782	104.2	24.20	2230	105.0	23.55	2130
19.	76.6	36.625	5.875	105.0	25.30	2375	106.4	24.85	2280
20.	71.5	38.625	5.970	104.0	29.10	2684	104.8	28.30	2400
21.	68.2	40.225	5.937	105.0	30.80	2840	105.0	29.90	2740
22.	6.2.0	41.500	7.125	103.0	33.50	3020	105.0	32.90	2960

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 60 ∞ , 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 105.

EXPERIMENT No.3. SHEET C.

APRIL 25, 1901.

CALCULATED DATA.

Table No. 11.

No. Obs.	R.P.M.	Pull in Pounds.	Torque	True Watts. Output.	Total True Watts. Input.	True Efficiency
	1.	2.	3.	4.	5.	6.
1.	1834	0	0	0	135	0
2.	1808	2.250	1.002	151	760	35.2
3.	1788	4.125	1.970	496	970	65.4
4.	1755	6.031	2.868	724	1110	74.7
5.	1730	7.031	3.350	835	1344	75.3
6.	1715	8.972	4.270	1054	1556	78.6
7.	1705	10.500	5.020	1220	1780	78.6
8.	1670	12.250	5.850	1392	2010	78.4
9.	1640	14.340	6.840	1620	2214	80.6
10.	1638	15.812	7.550	1768	2368	83.5
11.	1622	16.786	8.060	1850	2678	78.2
12.	1604	18.845	9.000	2002	2990	75.0
13.	1574	21.082	10.050	2250	3192	75.5
14.	1498	22.375	10.680	2345	3780	73.6
15.	1449	24.990	11.450	2498	4008	63.5
16.	1424	26.562	12.670	2558	4168	63.8
17.	1386	27.657	13.420	2628	4360	63.0
18.	1354	28.458	13.580	2632	4655	60.5
19.	1272	29.750	14.200	2682	5084	57.7
20.	1214	31.657	15.100	2688	5580	53.2
21.	1104	33.312	15.900	2700	5870	48.4
22.	1090	33.375	15.950	2460	5980	41.3

BRAKE TEST OF

WESTINGHOUSE 2 PHASE, 6000, 2 H.P. INDUCTION MOTOR.

IMPRESSED VOLTAGE 105.

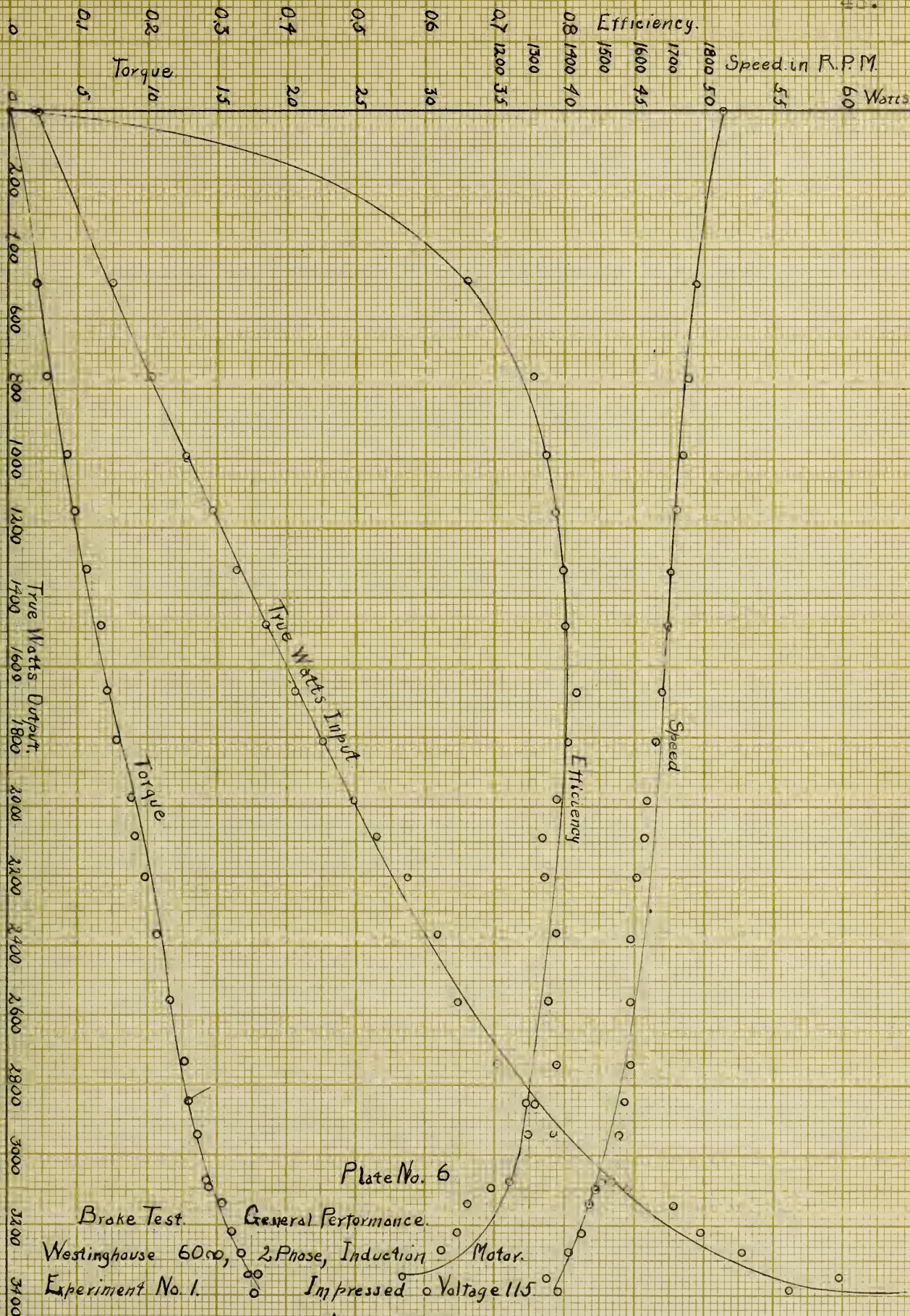
EXPERIMENT No.3. SHEET D.

APRIL 25, 1901.

CALCULATED DATA.

Table No. 12.

No. Obs.	Apparent Watts.	Power Factor	ϕ .	$\sin \phi$	$I \sin \phi$	$I \cos \phi$
	1.	2.	3.	4.	5.	6.
1.	557	0.185	$79^{\circ}23'$	0.983	5.22	0.98
2.	596	0.450	$63^{\circ}45'$	0.892	5.08	2.56
3.	683	0.666	$48^{\circ}41'$	0.745	4.82	4.32
4.	758	0.698	$44^{\circ}16'$	0.716	5.16	5.04
5.	820	0.732	$42^{\circ}56'$	0.681	5.31	5.70
6.	913	0.793	$37^{\circ}32'$	0.609	5.28	6.88
7.	993	0.834	$33^{\circ}29'$	0.551	5.20	7.87
8.	1127	0.826	$34^{\circ}18'$	0.563	5.97	8.80
9.	1239	0.849	$31^{\circ}53'$	0.528	6.42	10.02
10.	1287	0.898	$26^{\circ}6'$	0.439	5.38	11.00
11.	1412	0.885	$27^{\circ}44'$	0.465	6.28	11.90
12.	1558	0.885	$27^{\circ}44'$	0.475	6.89	13.10
13.	1730	0.890	$27^{\circ}7'$	0.455	7.47	14.60
14.	1860	0.885	$27^{\circ}44'$	0.465	8.24	15.65
15.	2190	0.880	$28^{\circ}21'$	0.474	9.92	18.40
16.	2338	0.878	$28^{\circ}35'$	0.478	10.60	19.50
17.	2440	0.872	$29^{\circ}18'$	0.489	11.38	21.17
18.	2562	0.870	$29^{\circ}32'$	0.492	12.08	21.40
19.	2730	0.868	$29^{\circ}46'$	0.496	12.88	22.55
20.	3118	0.863	$30^{\circ}20'$	0.505	15.42	26.40
21.	3310	0.859	$30^{\circ}47'$	0.511	16.02	26.98
22.	3560	0.855	$31^{\circ}14'$	0.518	17.74	29.50



Power Factor.
Amperes.

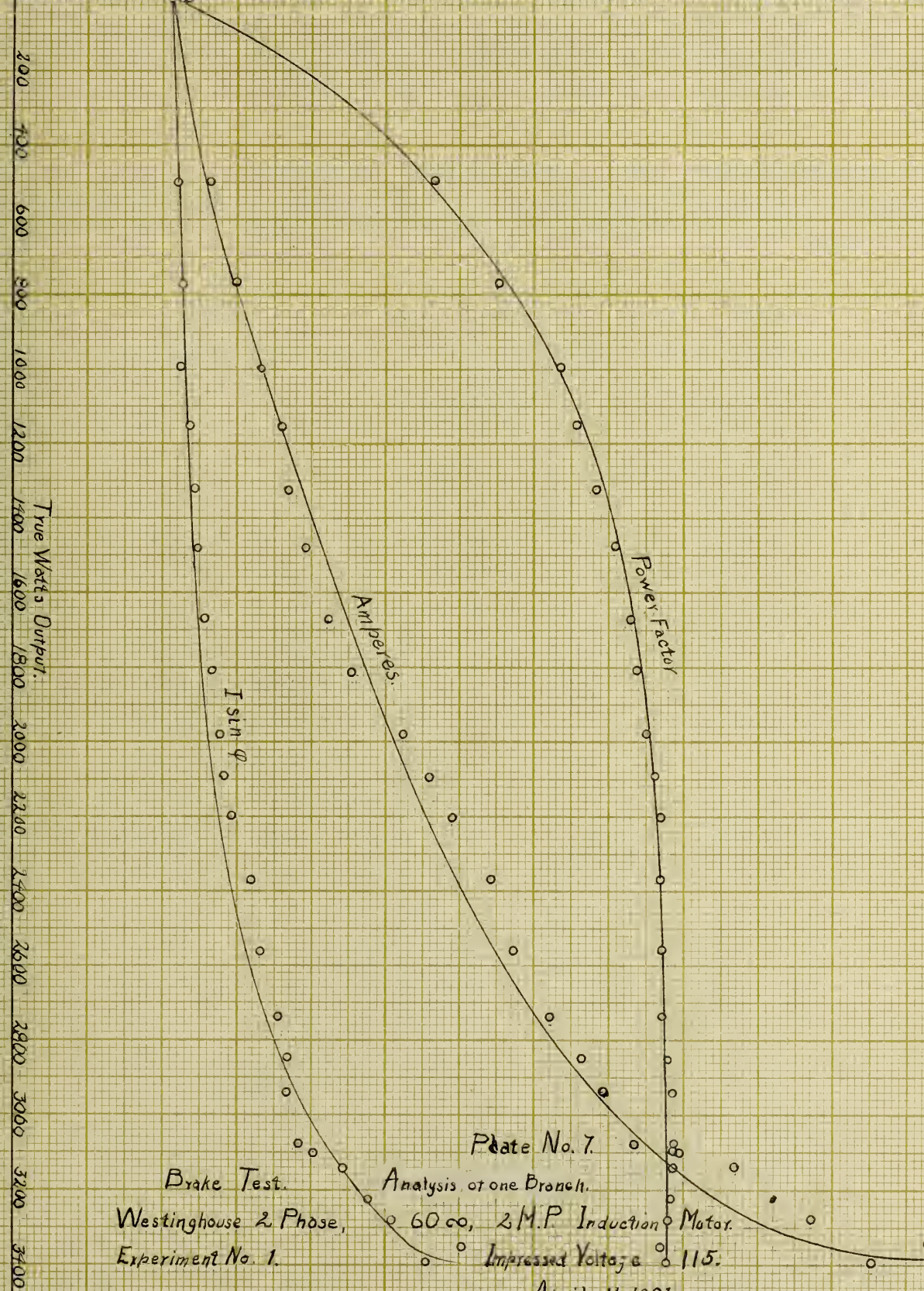


Plate No. 7.
Analysis of one Branch.
Brake Test.
Westinghouse 2 Phase,
Experiment No. 1.
60 cc, 2 M.P. Induction Motor.
Impressed Voltage 115.
April 11, 1901.

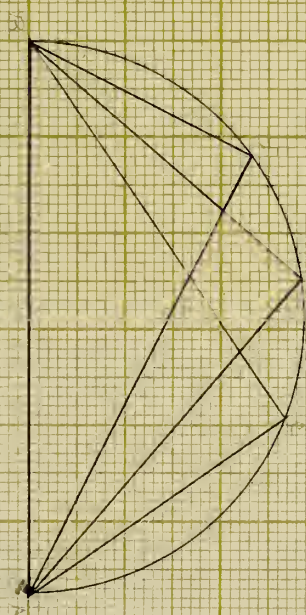
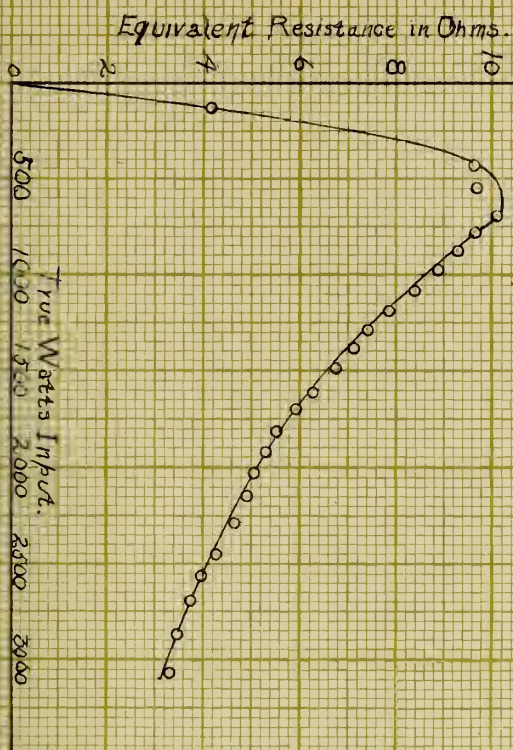


Plate No. 9.

Brake Test. Equivalent Resistance Analysis.
 Westinghouse 2 Phase, 6000, 2 H.P. Induction Motor.
 Experiment No. 1. Impressed Voltage 115.
 April 11, 1901.

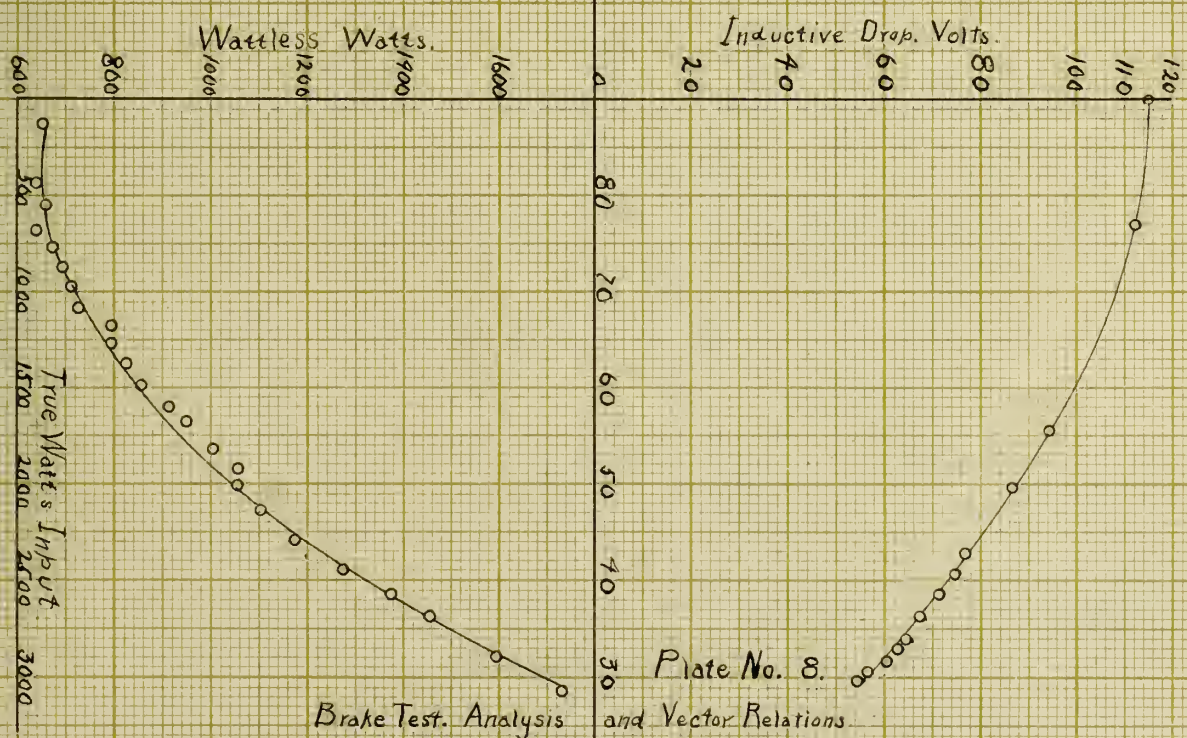
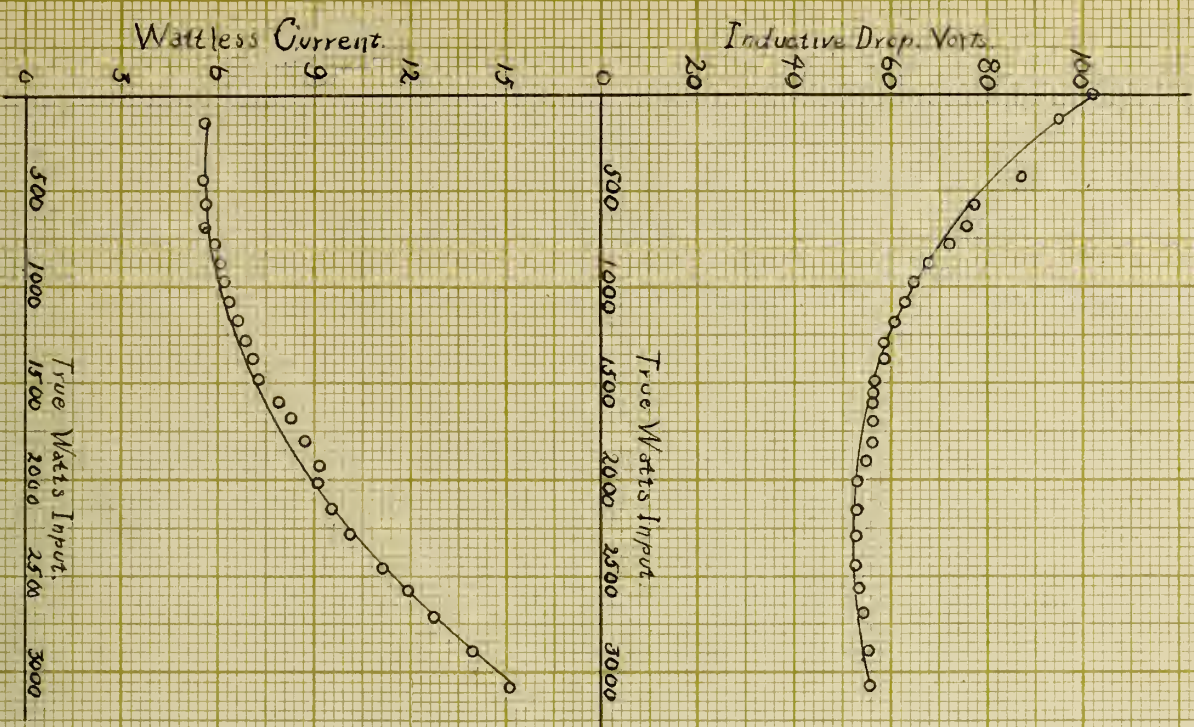


Plate No. 8.
 Brake Test. Analysis and Vector Relations.
 Westinghouse 2 Phase, 60 ϕ , 2 H.P. Induction Motor.
 Experiment No. 1. Impressed Voltage 115.
 April 11, 1901.

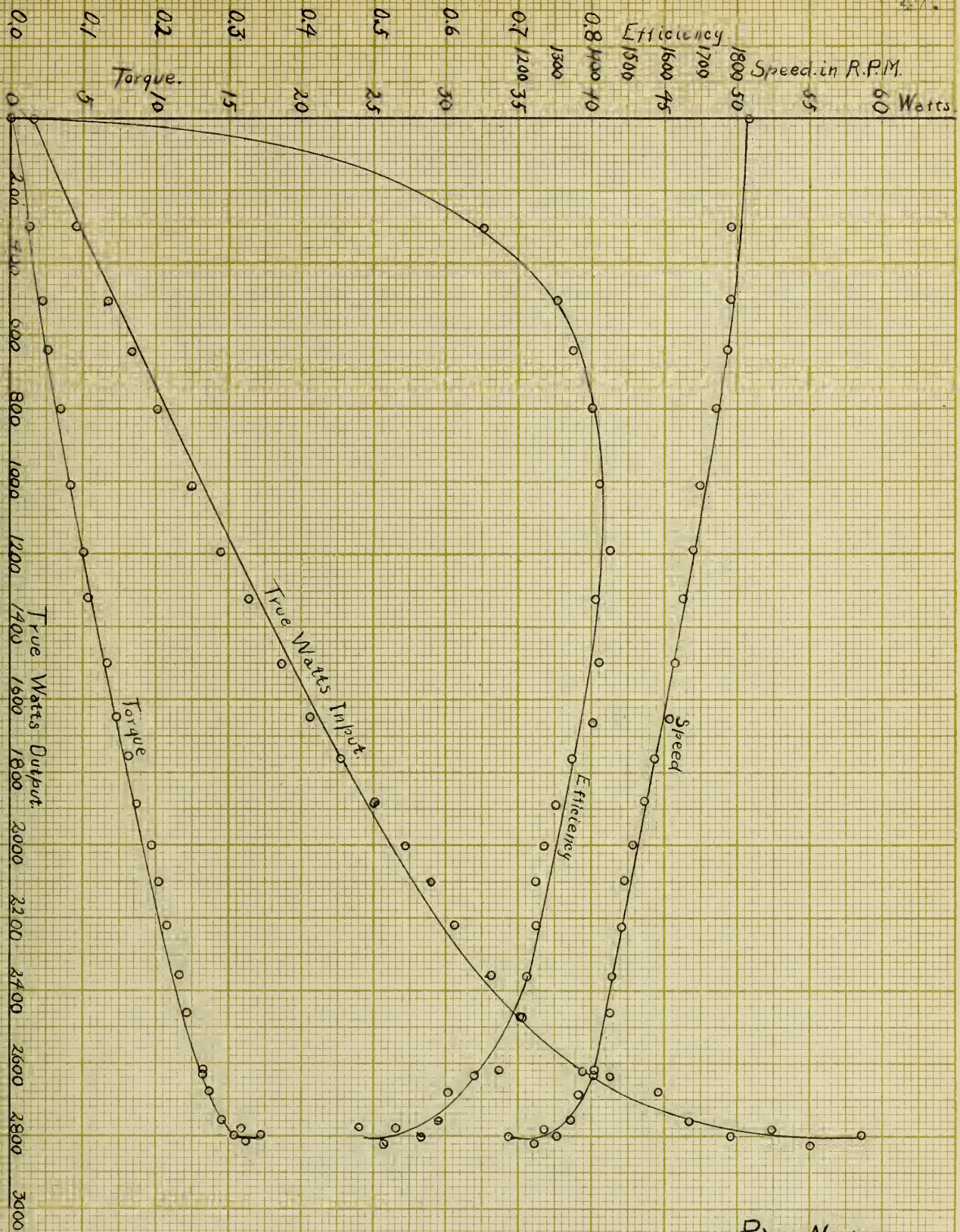


Plate No. 10.

Brake Test. General Performance.
 Westinghouse 2 Phase, 60 Hz, 2 H.P. Induction Motor.
 Experiment No. 2. Impressed Voltage 110.
 April 18, 1901.

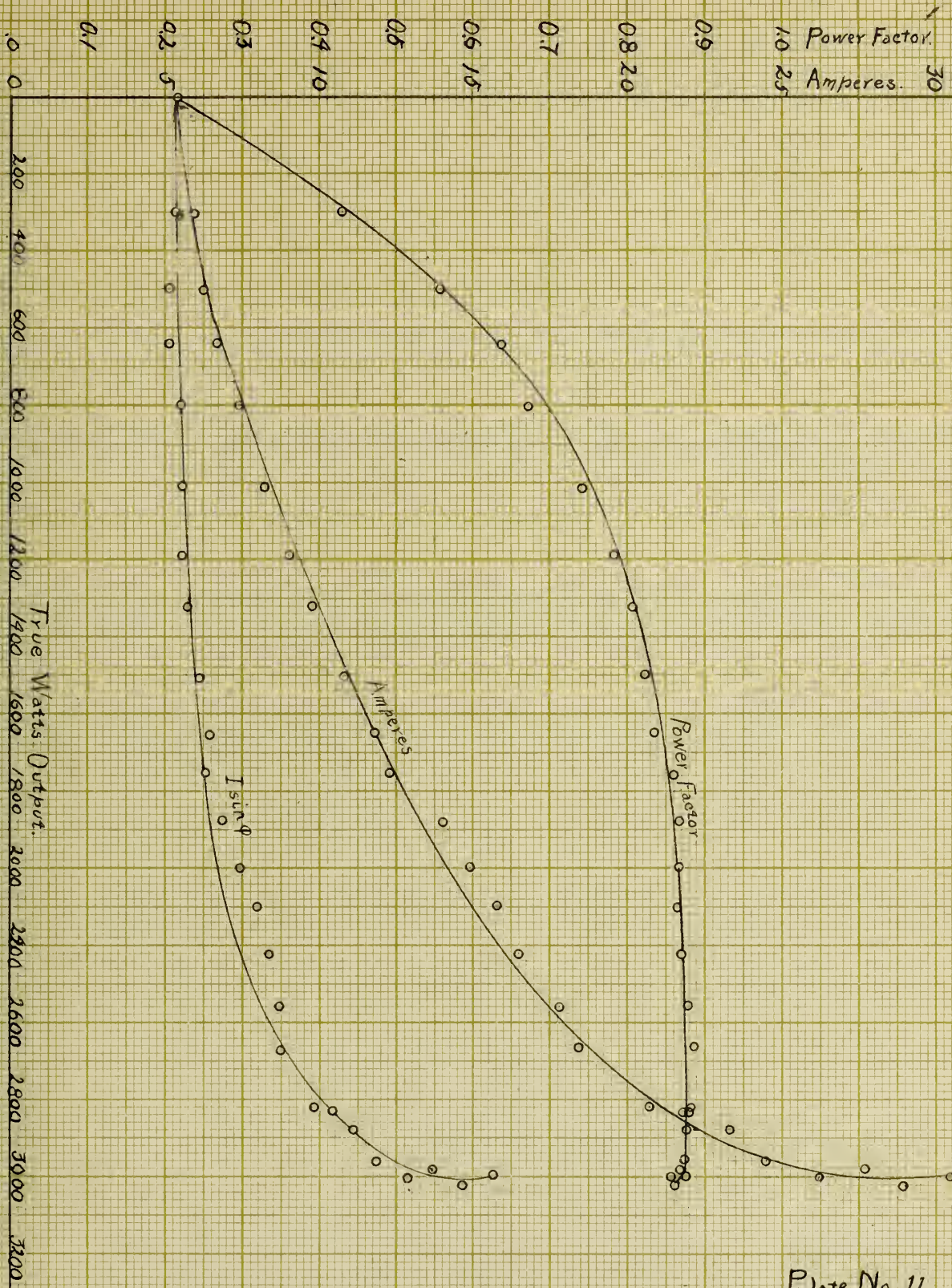


Plate No. 11.

Brake Test Analysis of one Branch.
 Westinghouse 2 Phase, 6000, 2 H.P. Induction Motor.
 Experiment No. 2. Impressed Voltage 110.
 April 18, 1901.

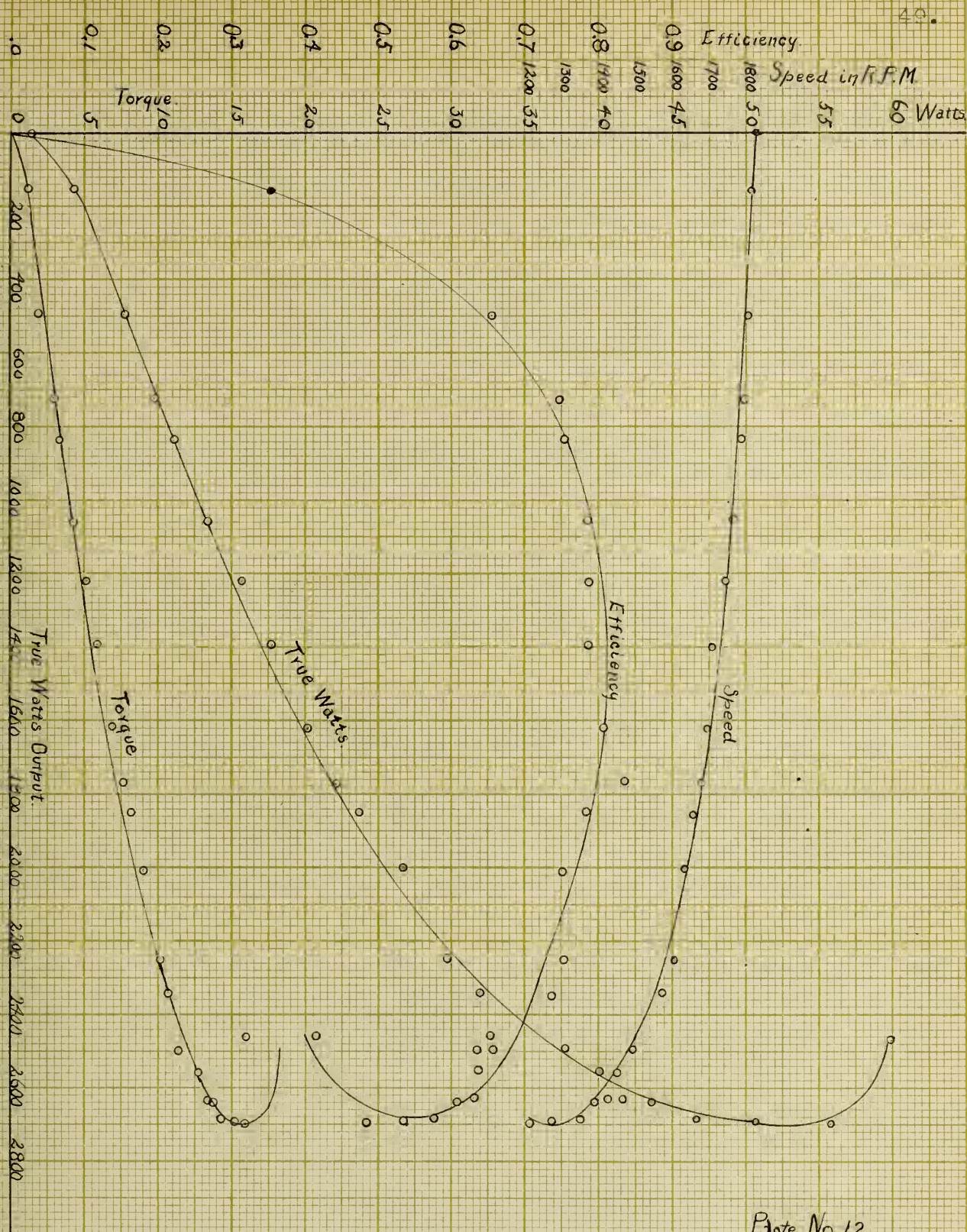
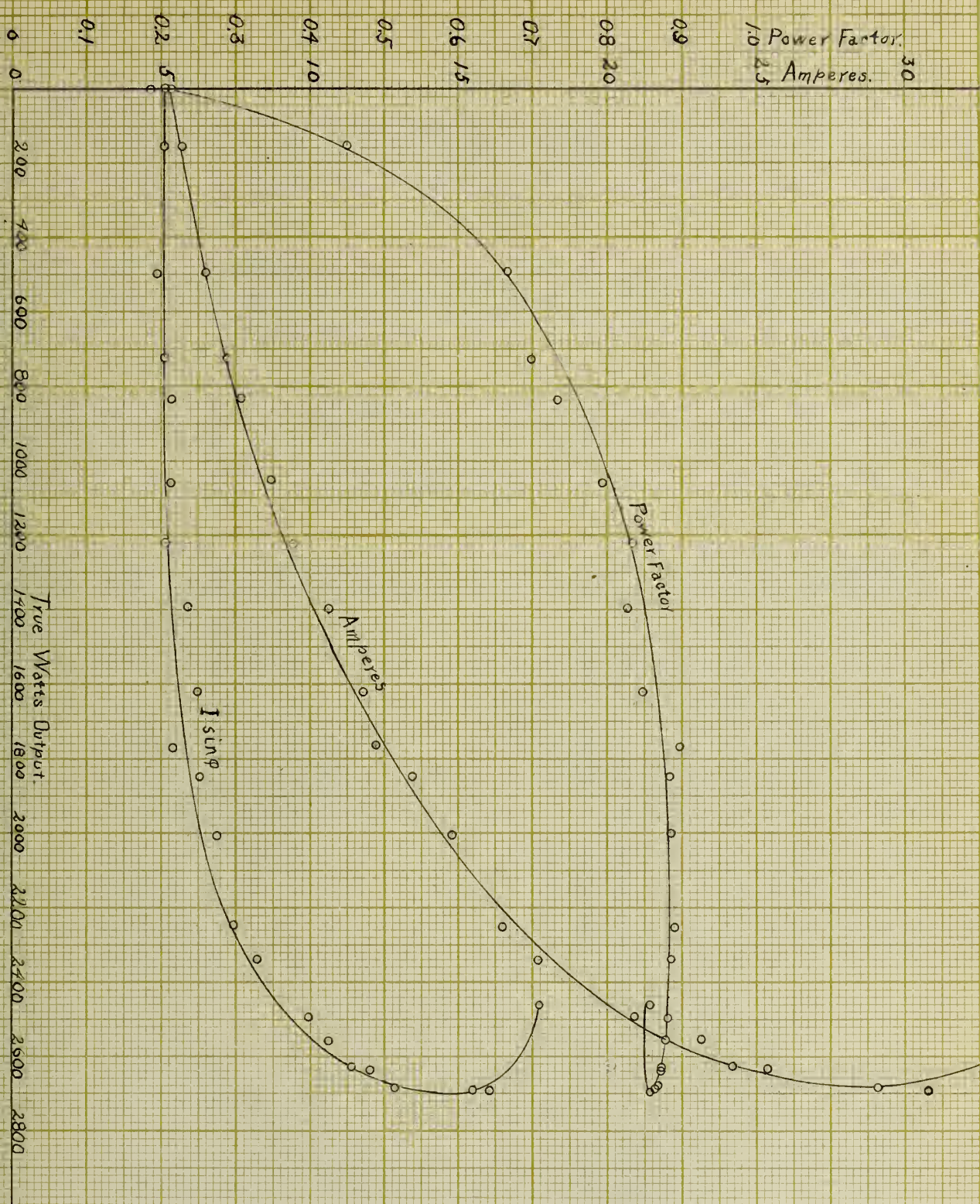


Plate No. 12

Brake Test. General Performance.
 Westinghouse, 2 Phase, 6000, 2 H.P. Induction Motor.
 Experiment No. 3. Impressed Voltage 105.
 April 25, 1901.



Broke Test. Analysis of one Branch. Plate No. 13
 Westinghouse, 2 Phase, 60 co, 2 H.P. Induction Motor.
 Experiment No. 3. Impressed Voltage 105.
 April 25, 1901.





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